SRR-87-06

Cracking of New Jersey Barrier Walls

Ontario Ministry of Transportation

Research and Development Branch

89-03228

Technical Report Documentation Page

Cracking of New Jersey Barrier Walls

Author:	T. Tharmabala
MTO No.:	SRR-87-06
Date:	December 1987
MTO Contact:	T. Tharmabala
Published by:	The Research and Development Branch Ontario Ministry of Transportation
Participating Agencies/-Client:	
Abstract:	Cracking of barrier walls at locations other than the construction joint is a common problem. These cracks cause and accelerate the deterioration of barrier walls. Various bridges were surveyed for barrier wall cracking. Those surveys included barrier walls constructed using the a) V-notch construction joint, b) V-notch and saw cut, c) V-notch and asbestos crack inducer and d) Alternate panel construction. This report discusses in detail the mechanism involved in the barrier wall cracking and the means by which it can be reduced.
Key words:	computer-based traffic model, freeway traffic corridors, travel time, queueing analysis
Comments:	
Distribution:	Unrestricted, MTO H.O. and Regions, selected structural and maintenance engineers
Copyright Status:	Crown copyright

SRR-87-06

Cracking of New Jersey Barrier Walls

T. Tharmabala

Published by
The Research and Developrnent Branch
Ontario Ministry of Transportation
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Published without prejudice as to the application of the findings. Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the Ministry.

For additional copies, contact:
The Editor, Technical Publications
Ministry of Transportation
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 235-7635
Infotex electronic mail: 23: MIN006

December 1987

Table of Contents

1/ Introduction	1
2/ Survey of Barrier Wall Cracking	2
3/ Mechanism of Barrier Wall Cracking	4
4/ Means of Reducing Wall/Slab Cracking	7
5/ Conclusions	9
6/ References	10

List of Figures

1a/ Boviard, Highway 410	11
1b/ Highway 7, Highway 410	12
2a/ Highway 410, CN Rail Overpass	13
2b/ Heartlake Road, Orenda Road	14
3a/ St Jones Road, East York	15
3b/ Highway 7, Dufferin Street	16
3c/ Astorville Bridge	17
4/ Progress Cracking of a Symmetrical Beam	18
5a/ Barrier Wall Details, Type 1	19
5b/ Barrier Wall Details, Type 2	20
5c/ Barrier Wall Details, Type 3	21
6/ Distribution of Shrinkage Stresses in Barrier Walls	22
7/ Tensile Stresses Developed in the Deck by the Barrier Walls	23
8/ ε_{sh}/K_{ct} Related to Concrete Age	24
9/ Proposed Reinforcement Details	25

1/ INTRODUCTION

New Jersey barrier walls are commonly used with concrete bridges or on other bridges with concrete decks. These walls are used to provide protection to vehicles accidently moving off course and to pedestrians using the sidewalk. Structurally, these barriers and their connections to the deck are designed to sustain the accidental loads imposed by the vehicles. These accidental loads are specified in the OHBDC [1]. The barriers have a standard detail and the method of construction and concrete to be used is specified in the structural standards [2].

Barriers generally extend a few metres beyond the end of the bridge and have expansion joints where the bridge beneath them do. In between the expansion joints there are construction joints. The construction joints usually have continuous reinforcement. Shrinkage movement of the barrier walls is allowed by letting the concrete crack vertically at the construction joint locations. The old method was to use a V-notch to induce cracking. Most of the time the cracking did not occur at the V-notch. This caused random cracking at locations between the V-notches. The barriers were saw cut (without cutting the reinforcement) at the construction joint locations. The saw cutting was performed soon after the formwork was removed. This approach did not remedy the problem. Crack inducement using a V-notch and asbestos packing showed little or no vertical cracking at locations other than the construction joints. In bridges with thick slabs (for example, post-tensioned decks), the cracks stopped at the barrier/slab interface; for thin slabs (e.g., 225 mm concrete deck) the cracks extended well into the deck slab.

Currently, MTO is using alternate panel construction to reduce the shrinkage cracking of barrier walls. Since this was only introduced recently the performance of these barriers has not been evaluated completely.

This report presents a survey of barrier wall cracking for barriers constructed using the above methods. The advantages and disadvantages of each of the methods used are discussed. The advantage of using additional longitudinal reinforcement to redistribute the shrinkage stresses is also investigated.

2/ SURVEY OF BARRIER WALL CRACKING

The crack survey shown in Figures 1a and b are for post-tensioned bridges located at Bovaird, Highway 410 Highway 7, and Highway 410, respectively. For the Bovaird bridge, only V-notching was used: for the Highway 7 bridge, both V-notching and saw cutting were used. In both cases, considerable vertical cracking of the barrier walls was observed. The cracks appeared near the centre length between each construction joint. The cracks usually form near the top face of the barrier wall and travel downwards. The length of the cracks differed but they invariably stopped at the barrier-deck interface. The crack widths were less than 0.05 mm for the Bovaird bridge and less than 0.15 mm for the Highway 7 bridge. The Highway 7 barrier walls showed considerable map cracking which was not present on the Bovaird bridge. This could be due to improper curing or to the use of poor concrete. The barriers cast for the Burlington Skyway bridge also used V-notches to introduce barrier wall cracking. Looking underneath the bridge during a visual survey showed that the barrier and the deck slab are cracked at the construction joints and other locations.

Figures 2a and b illustrate the barrier wall cracking observed on the Highway 410, CN Rail overpass bridge and the Heartlake, Orenda bridge, respectively. For these bridges the contractors used V-notches and asbestos packing to introduce cracking. As is evident from the crack survey, this method almost eliminated barrier wall cracking at interior locations. However, cracks were found in the deck slabs at construction joints. Water and salt seepage through the deck was evident at crack locations. Although a crack survey of a bridge having a thick slab (e.g., a post-tensioned deck) and using the above crack inducer is not available, it is thought that a thicker slab, with its additional longitudinal reinforcement would not crack.

The crack survey performed on bridges using alternate panel construction is given in Figures 3a, b and c. The first bridge has a post-tensioned bridge deck and the barrier wall showed some vertical cracking. Apparently, the number of cracks observed in this bridge is greater than those found on bridges where V-notch and asbestos crack inducers are used. The Highway 7, Dufferin bridge showed no cracking in the barrier walls or the slab. The slab had a raised sidewalk on both sides of the

bridge and the slab near the barrier walls was 450 mm thick. However, with thin slabs slab cracking is predominant.

Cracks observed on the Astorville Road interchange are shown in Figure 3c. This is a two-span steel girder bridge with a concrete deck. The barrier walls were poured in alternate panels and there is no reinforcement at the construction joints. The survey showed no cracks in the barrier walls. However, at the centre support (i.e., the negative moments area) the construction joint cracks continued into the deck slab. A survey of the White Clay River bridge showed a few cracks at the 1/3 points of some panels. This bridge is also a steel girder bridge with thin deck slabs.

The crack survey shows that the crack widths involved are of a minor nature and are not reducing the intended performance of the barriers. The only concern is that performance could be affected in the long-term. The water seepage visible on the slabs indicates that the slab cracking requires immediate attention.

3/ MECHANISM OF BARRIER WALL CRACKING

Concrete shrinks when placed in a dry environment. For all practical purposes, it can be assumed that concrete will begin to shrink on the completion of its casting. The magnitude of concrete shrinkage depends on the composition of the concrete and the environmental conditions. The shrinkage increases linearly with the concrete paste content and aggregate shrinkage. Normal aggregates have low to medium shrinkage values. The magnitude of concrete shrinkage reduces with increasing relative humidity.

Restraint of concrete shrinkage induces tensile stresses in the concrete. Concrete will crack when the induced stresses are greater than the tensile strength of the concrete. Consider a reinforced concrete tension member with symmetrical tension reinforcement as shown in Figure 4. The bond between the reinforcement and the concrete introduces restraint on the concrete shrinkage movement. The bond slip and the creep effect help to reduce tensile stresses. The bond slip at the ends is greater than at the mid portion. This makes the middle section most critical for cracking. As a result, the first crack forms at a crack-prone section (i.e., the section with lower tensile strength) closer to the middle section. This cracking relieves some of the tensile strains on the concrete; however, further shrinkage now causes cracking at the middle of the two portions adjoining the first crack. This process continues until the tensile stresses induced do not exceed the tensile strength of the concrete.

The restraint to the shrinkage of New Jersey barriers is provided by the bridge deck and longitudinal reinforcement in the barrier wall. The details of the most commonly used barrier walls and their reinforcement are as given in Figure 5. The reinforcement percentage is very low and the restraint provided by the steel bars is considered small compared to that provided by the bridge deck. The restraint at the barrier's base causes unequal shrinkage of the barrier. The longitudinal reinforcement detailing for the barrier used shows there is very little or no

reinforcement provided at the top face of the barrier. This causes additional shrinkage of the top face area, and additional shrinkage stress to those developed by the base restraint. The stress distribution on the barrier is illustrated in Figure 6. Clearly, the top face is the weakest link in the barrier wall. Additional reinforcement, closer to the top face, is needed to reduce the differential shrinkage and to distribute shrinkage stress.

The base of the barrier can be considered fully restrained by the concrete deck (though there may be some initial bond slippage during the hardening of concrete), so cracking will occur early on. In fact, cracks must appear at the base level first. This results in a large number of invisible, closely spaced cracks.

Consider the case in which a barrier is cast over a thick slab (post-tensioned deck). The barrier wall shrinkage compresses the deck and the restraint provided by the deck causes cracking at the centre. Cracking relieves some of the tensile and compressive stresses induced in the barrier and deck, respectively. Now the two portions of the wall adjoining the first crack shrink independently. This gives rise to tensile stresses in the deck, maximum stresses being in the deck section below the first crack formation. When this tensile stress exceeds the tensile strength, the deck cracks. For thicker decks this stress can be lower than the tensile strength value. For thin slabs, the tensile stress could exceed the tensile strength, leading to crack formation.

The shrinkage strains in the large or small panel are of the same order (i.e., they are independent of the length of panel). The initial slip of the barrier can, however, be relatively higher for a short panel than for a long one. This helps to reduce the tensile stresses induced on the barrier walls. The other advantage of using alternate panel construction is that, unlike the V-notch types, for which crack formation depends on the random effects of concrete shrinkage, the location of the lowest tensile strength, and the tensile strength reduction effect of the V-notches, alternate panel construction introduces a gap at each of the construction joints. It appears, however, that the tensile stresses induced in the deck by concrete shrinkage (ignoring the bond slip reduction) are only moderately reduced.

Compare two barriers of equal length as shown in Figure 7: one cast using construction joints and the other using alternate panels. Assume the barrier has seven panels and each half panel causes a tensile stress of T in the deck and that this stress is effective for three panel lengths only. The maximum tensile stress induced on the deck for continuous casting is 4.5T, while for a barrier with alternate panels it is 3T. The compressive stresses induced on the continuous deck before the first crack formation would reduce the tensile stress value of 4.5T.

4/ MEANS OF REDUCING BARRIER WALL/SLAB CRACKING

The formation of vertical cracks between the construction joints is reduced considerably by the use of:
a/ V-notch and asbestos packing, or
b/ alternate panel construction.

The use of alternate panel construction has a definite advantage over that of V-notch and asbestos packing in that the alternate panels are cast with a definite break at the construction joint locations. Therefore, the current practice of using alternate panel construction can be used for future barrier wall construction. However, formation of interior vertical cracks at the top face, where stresses are critical, can be reduced by using additional reinforcement there. Currently, the specifications for top faces provide very little reinforcement.

Odman (3) proposed an equation, given below, which relates concrete shrinkage, tensile strength, and bond restraint/slip parameters in a symmetrically reinforced beam.

$$\frac{\varepsilon_{sh}}{K_{ct}} > \frac{1}{\mu E_s}\left(1 + m\,\mu + \frac{mk\,A_s}{\rho\, r\ell}\right) \qquad (1)$$

where: ε_{sh} = concrete shrinkage
K_{ct} = concrete tensile strength
A_s = steel area
μ = reinforcement ratio
ℓ = twice effective embedment length
ρ = total perimeter of steel used
E_s = elastic modulus of steel
m = unknown constant
k/r = unknown constant

The concrete cracks when $\varepsilon_{sh}/\kappa_{ct}$ exceeds the value of the right-hand side of Equation 1. Using the m and k/r values used by Odman for symmetrically reinforced concrete beams, the $\varepsilon_{sh}/\kappa_{ct}$ values were calculated for various ages. The reinforcement ratio was taken to be 0.3, 0.6, and 0.8%. These values are given plotted against the concrete age in Figure 8. The Figure shows that the $\varepsilon_{sh}/\kappa_{ct}$ values decrease with the increase in steel percentage. This means that with a higher percentage of steel, the concrete will crack at a greater number of locations. This gives rise to cracks which are closely spaced, not visible, and resistant to environmental deterioration.

Crack formation in thin slabs can be reduced by increasing the amount of longitudinal steel provided. Using a higher number of small bars is beneficial since this increases the bond force developed between the steel and the concrete. The $\varepsilon_{sh}/\kappa_{ct}$ relationship shows that the use of a steel area of greater than 0.6% (the minimum longitudinal steel area currently required for deck slabs) achieves only a small increase in restraint and is therefore considered adequate to reduce barrier and slab cracking. A suitable arrangement using a 0.6% barrier wall reinforcement and a thin concrete deck is given in Figure 9.

5/ CONCLUSIONS

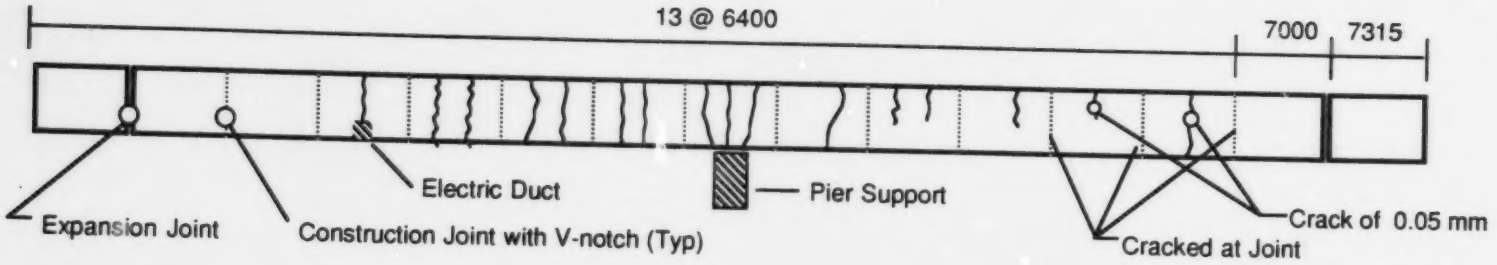
The formation of vertical cracks in New Jersey barrier walls in locations other than construction joints is reduced substantially by the use of V-notch and asbestos crack inducers or by using alternate panel construction. The use of V-notch and asbestos crack inducer introduces cracking in thin deck slabs (i.e., a 225 mm deck). The advantage of using alternate panel construction is that it provides a definite break in the barrier walls at construction joints. Use of additional longitudinal reinforcement in the barrier walls could further reduce the formation of stray vertical cracks. The area of longitudinal steel provided in the deck slabs is adequate; however, small diameter bars should be used to provide a better steel distribution.

6/ REFERENCES

1/ Ontario Highway Bridge Design Code (OHBDC), Ontario Ministry of Transportation and Communications, Downsview, Ontario.

2/ MTC Structural Manual, Ontario Ministry of Transportation and Communications, Downsview, Ontario.

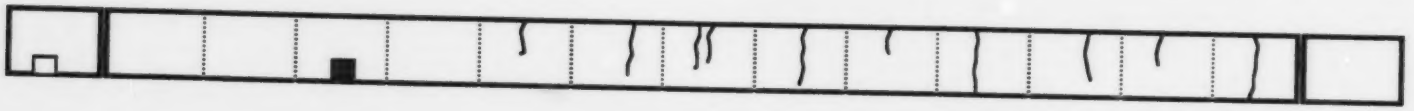
3/ Odman, S.T.A., Crack Formation due to Shrinkage of Reinforced Concrete. Rilem Bulletin, New Series, Part 9, 1960, pp. 100-109.



WEST

North Parapet

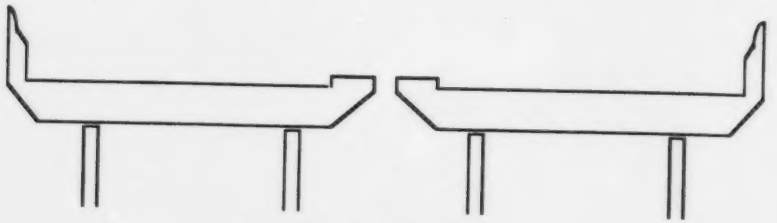
EAST



South Parapet

STRUCTURAL DETAILS

- Post tensioned deck, two span continuous
- Span length, etc., not known



BRIDGE CROSS-SECTION

Figure 1a/ Bovaird, Highway 410

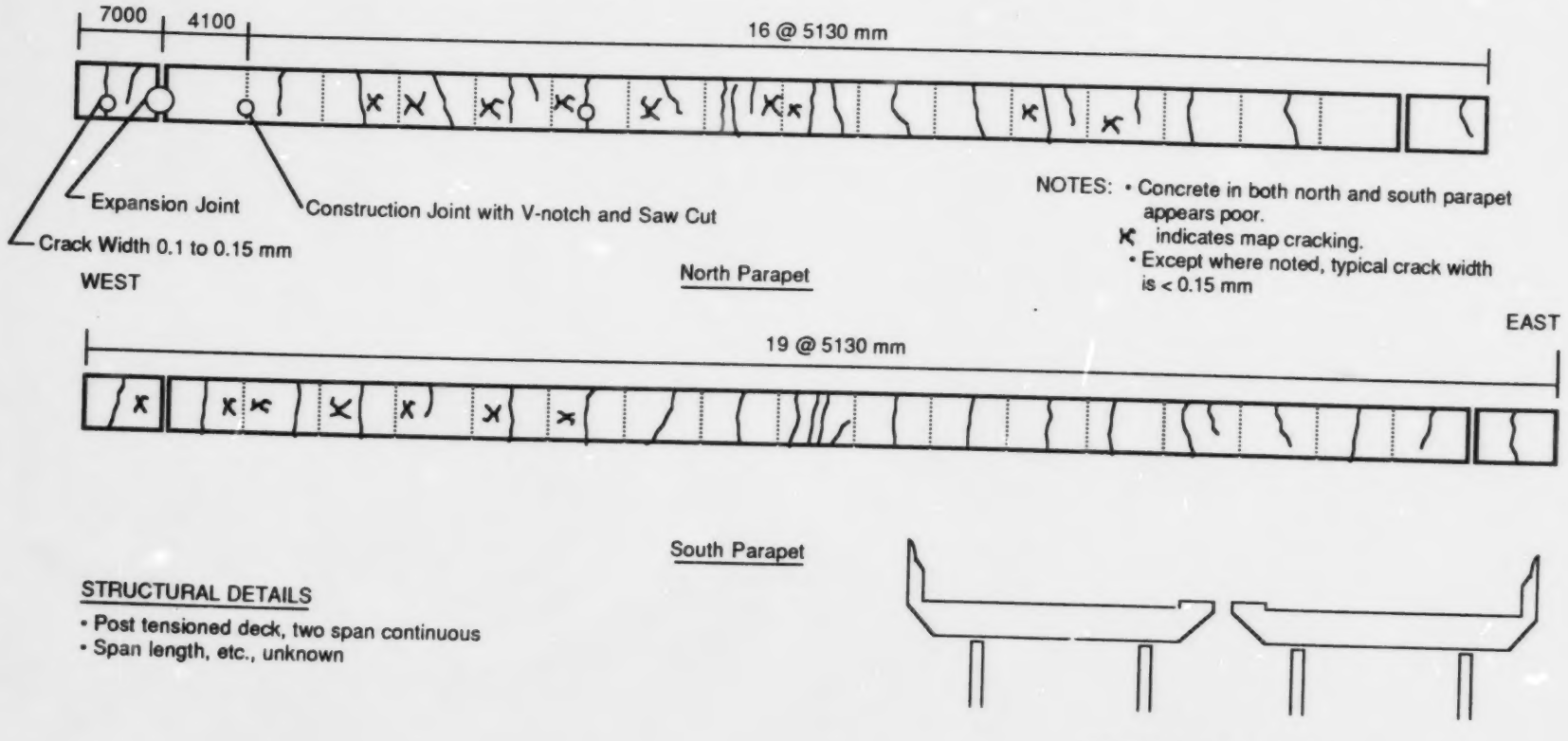

7000
4100
16 @ 5130 mm
Expansion Joint
Construction Joint with V-notch and Saw Cut
Crack Width 0.1 to 0.15 mm
WEST
North Parapet
NOTES: • Concrete in both north and south parapet appears poor.
indicates map cracking.
• Except where noted, typical crack width is < 0.15 mm
EAST
19 @ 5130 mm
South Parapet
STRUCTURAL DETAILS
• Post tensioned deck, two span continuous
• Span length, etc., unknown
BRIDGE CROSS-SECTION

Figure 1b/ Highway 7, Highway 410

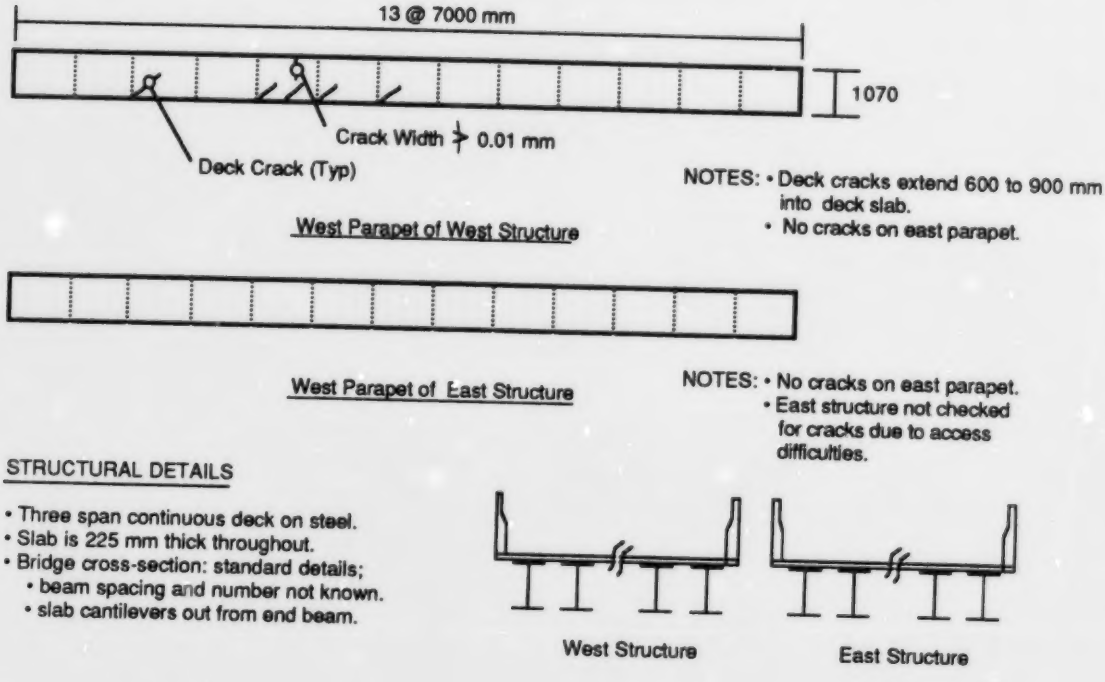
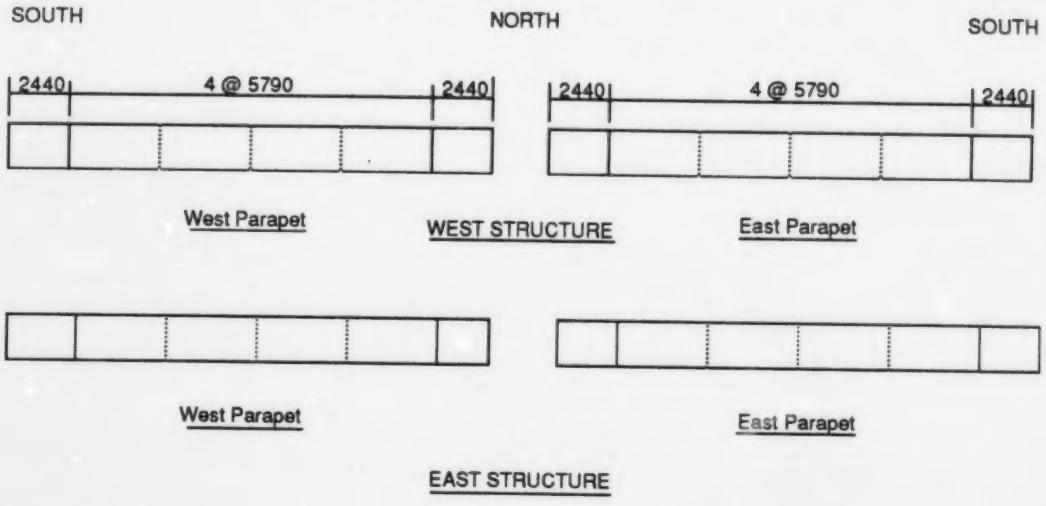

13 @ 7000 mm
1070
Crack Width ≥ 0.01 mm
Deck Crack (Typ)
West Parapet of West Structure
NOTES: • Deck cracks extend 600 to 900 mm into deck slab.
• No cracks on east parapet.
West Parapet of East Structure
NOTES: • No cracks on east parapet.
• East structure not checked for cracks due to access difficulties.
STRUCTURAL DETAILS
• Three span continuous deck on steel.
• Slab is 225 mm thick throughout.
• Bridge cross-section: standard details;
• beam spacing and number not known.
• slab cantilevers out from end beam.
West Structure
East Structure

Figure 2a/ Highway 410, CN Rail Overpass



STRUCTURAL DETAILS

- Single span
- Pretensioned beam and concrete deck

NOTES:
- Both structures in very good condition; no cracking.
- Some honey combing.

Figure 2b/ Heartlake Road, Orenda Road

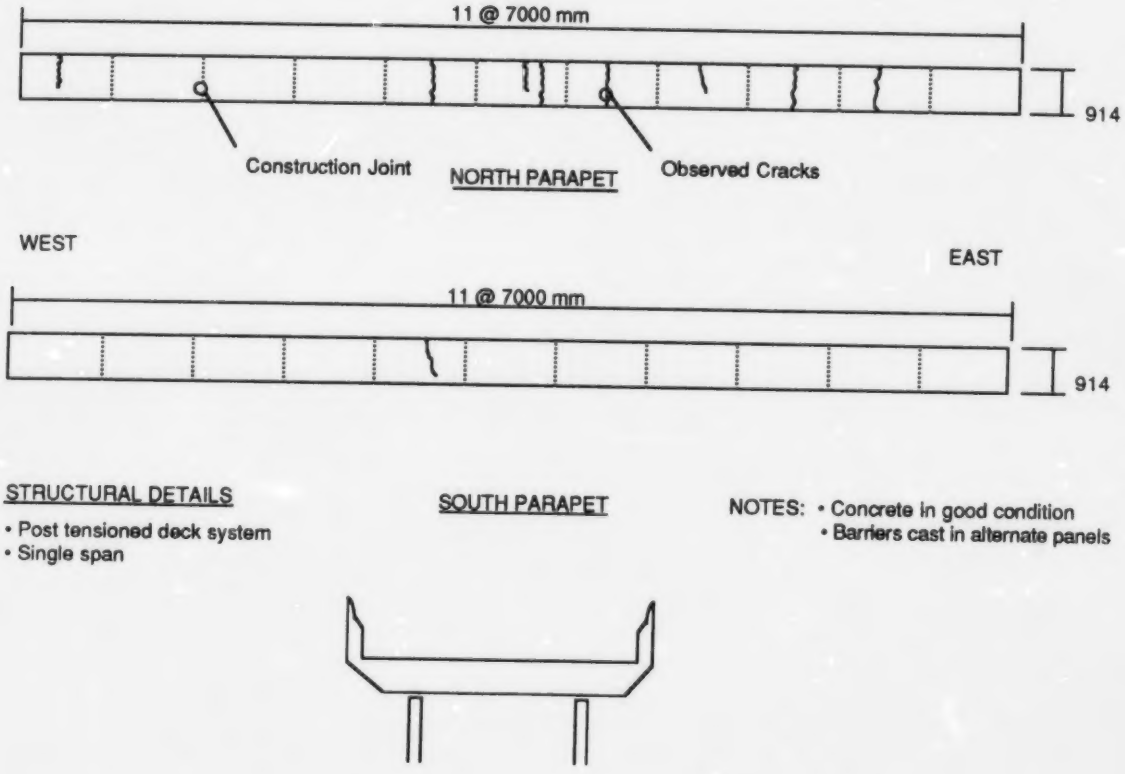
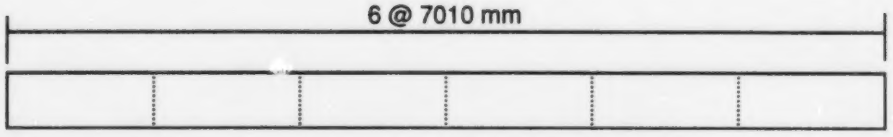
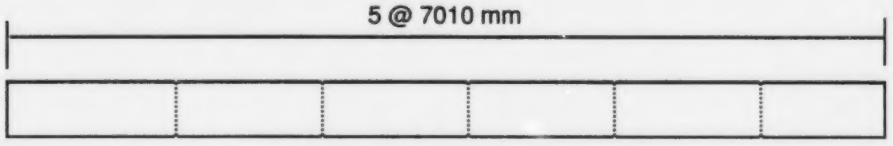


Figure 3a/ St. Jones Road, East York



NORTH PARAPET

WEST EAST



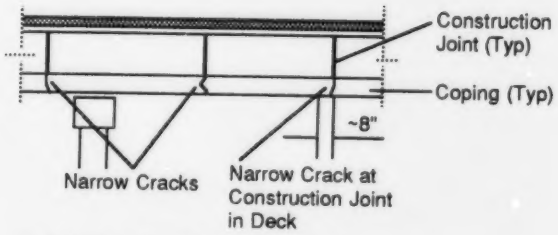
SOUTH PARAPET

STRUCTURAL DETAILS:

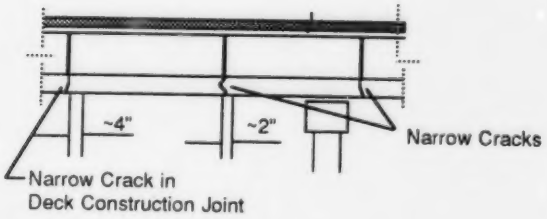
- Concrete slab on steel girders.
- Span length, girder spacing not known.

NOTES:
- No cracking, concrete in good condition.
- Barriers cast in alternate panels.

Figure 3b/ Highway 7, Dufferin

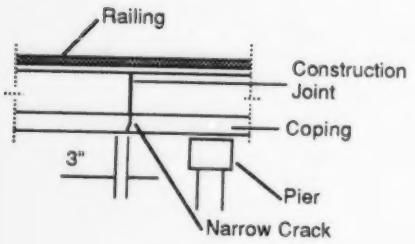


ELEVATED WEST BARRIER WALL

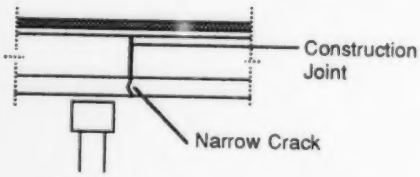


ELEVATED WEST BARRIER WALL

SOUTHBOUND BRIDGE



ELEVATED EAST BARRIER WALL



ELEVATED WEST BARRIER WALL

NORTHBOUND BRIDGE

Figure 3c/ Astorville Bridge

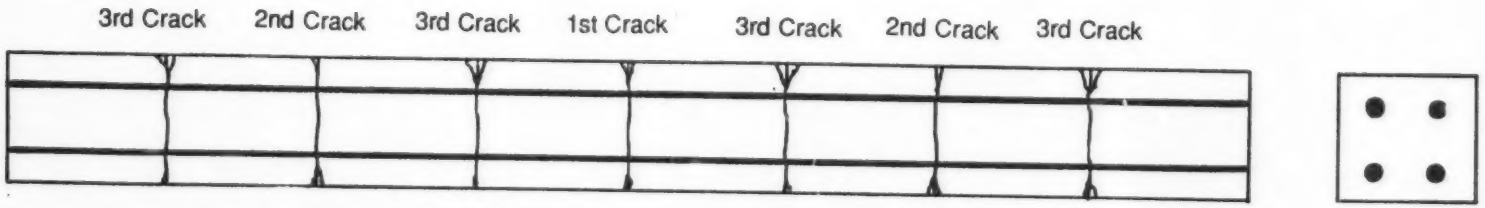
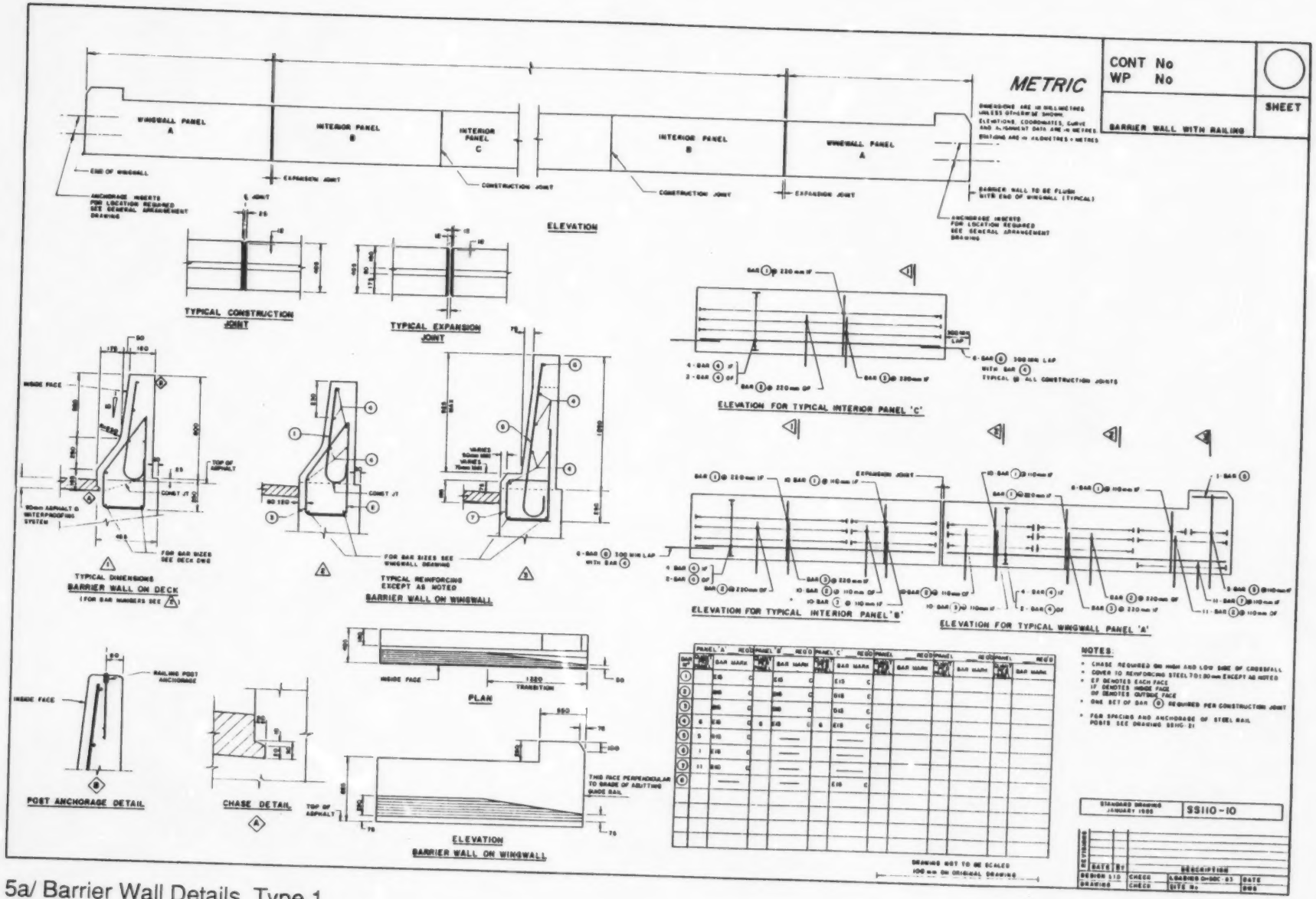
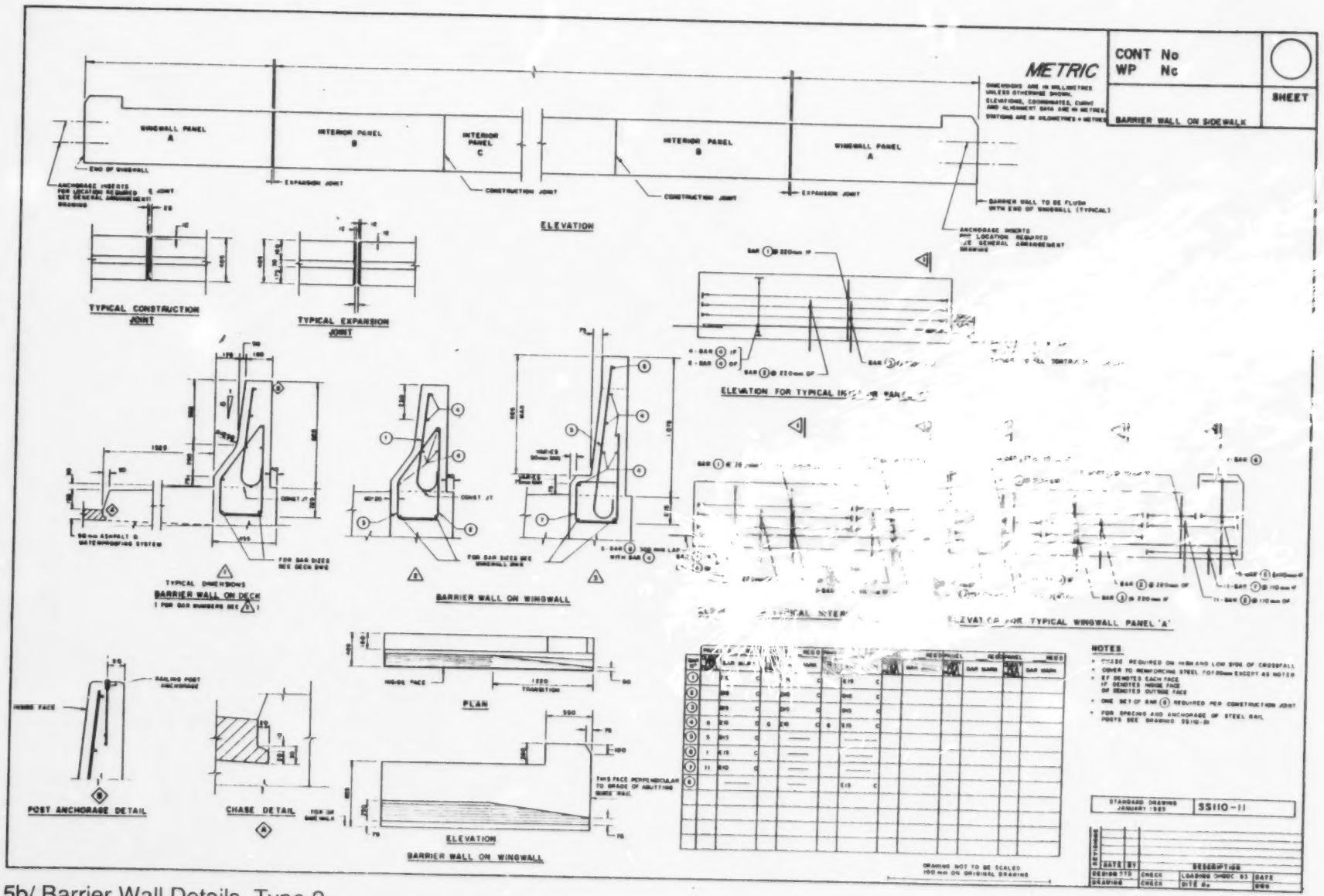


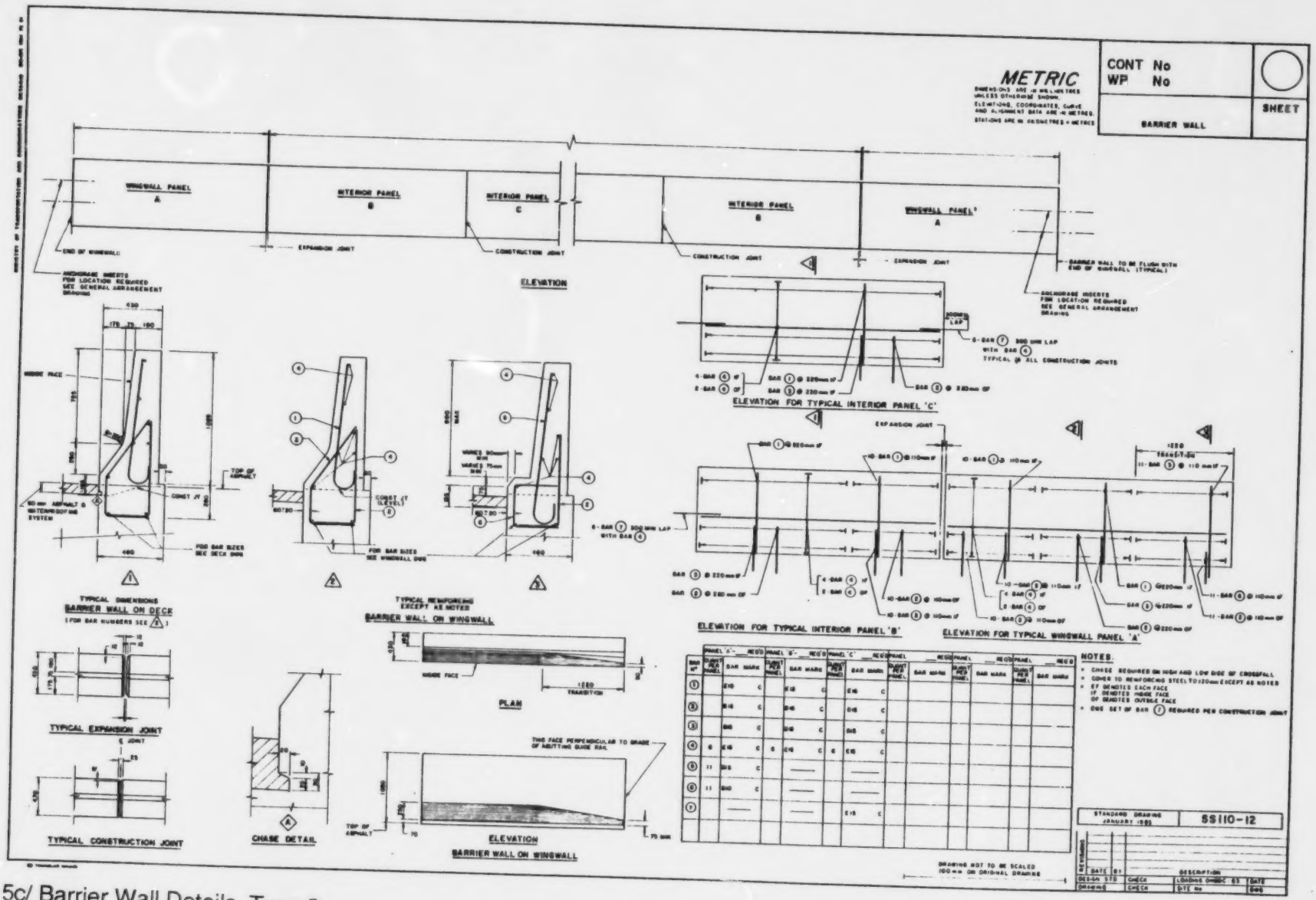
Figure 4/ Progress Cracking of a Symmetrical Beam



5a/ Barrier Wall Details, Type 1



5b/ Barrier Wall Details, Type 2



5c/ Barrier Wall Details, Type 3

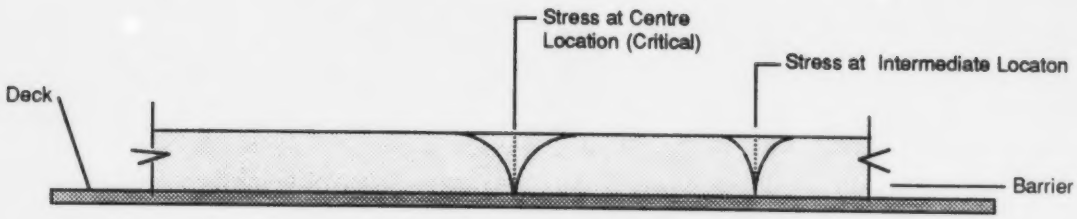
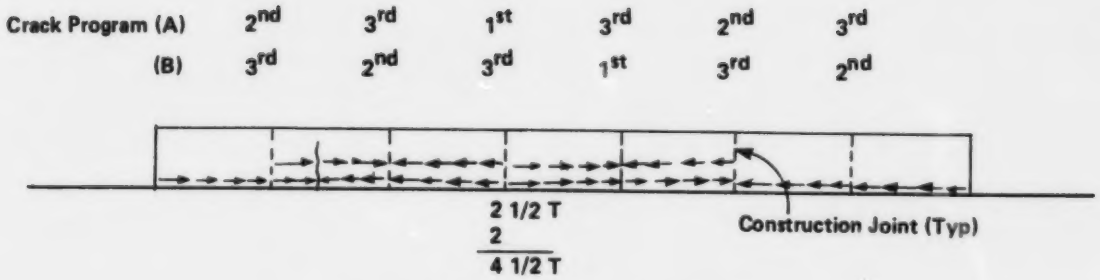
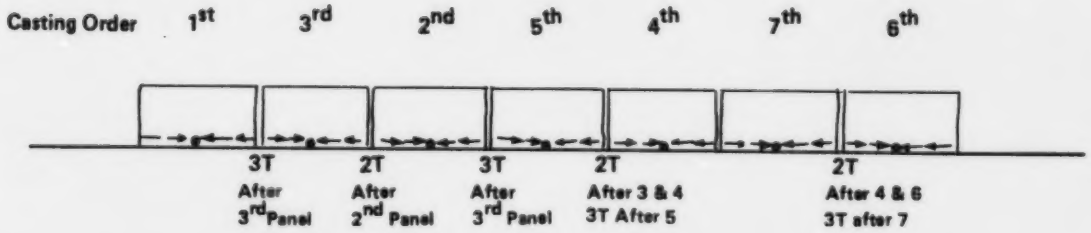


Figure 6/ Distribution of Shrinkage Stresses in Barrier Walls



CONTINUOUS PANEL CONSTRUCTION



ALTERNATE PANEL CONSTRUCTION

NOTE: Since an unequal Number of Panels are involved, the Crack Progress Can be Type A or B. Type A is Used for Tensile Stress Evaluation.

Figure 7/ Tensile Stresses Developed in the Deck by the Barrier Walls

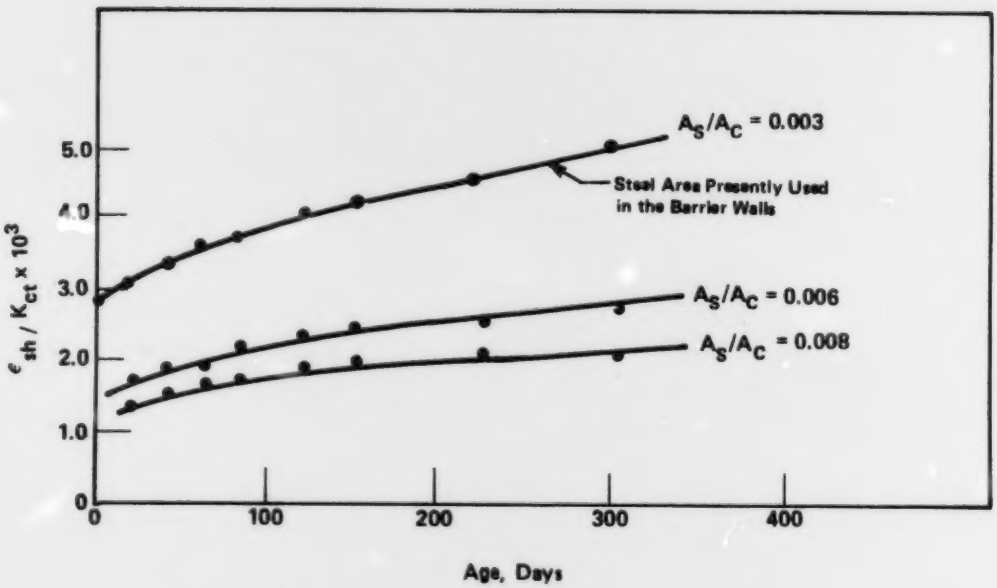


Figure 8/ ϵ_{sh} / K_{ct} Related to Concrete Age

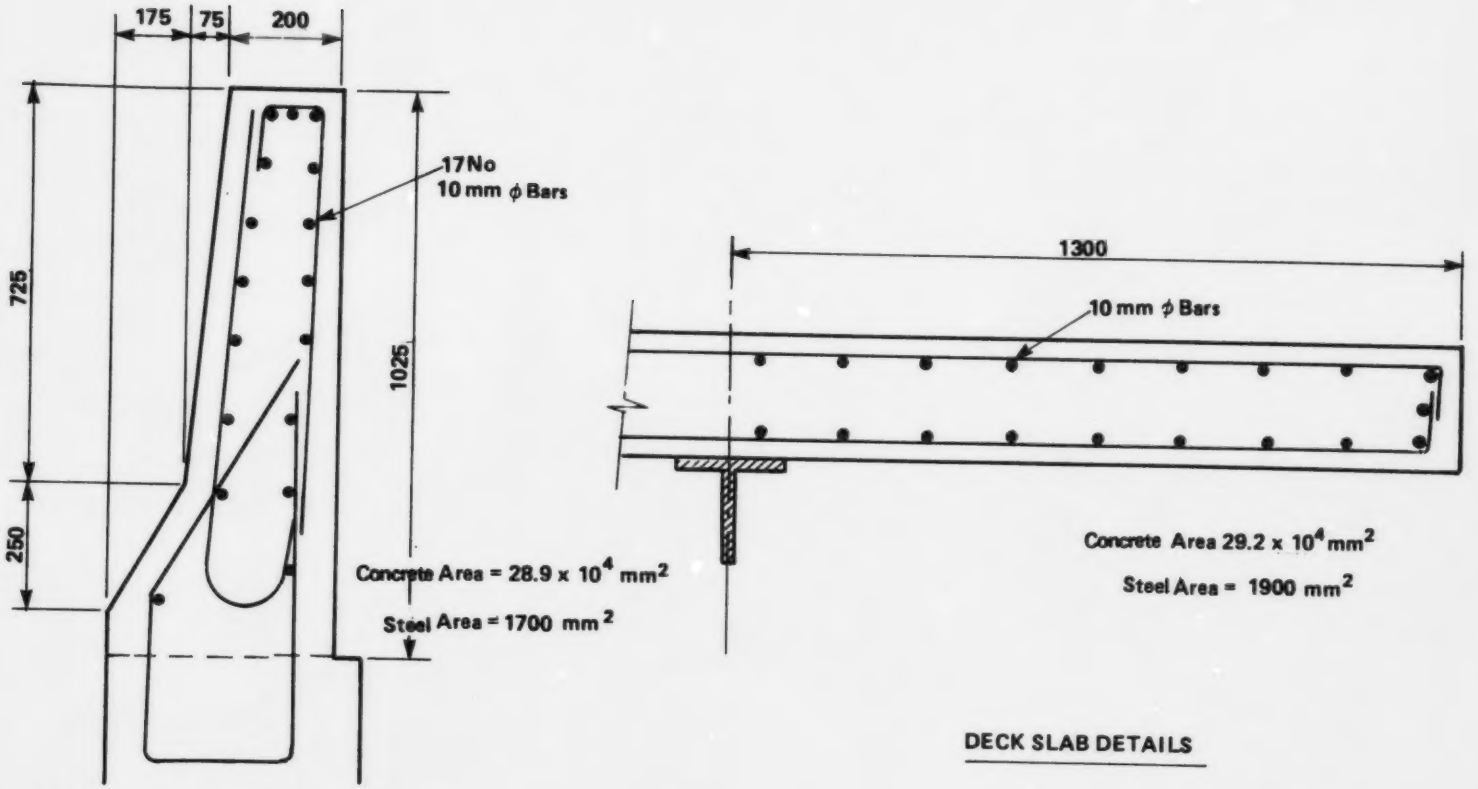


Figure 9/ Proposed Reinforcement Details